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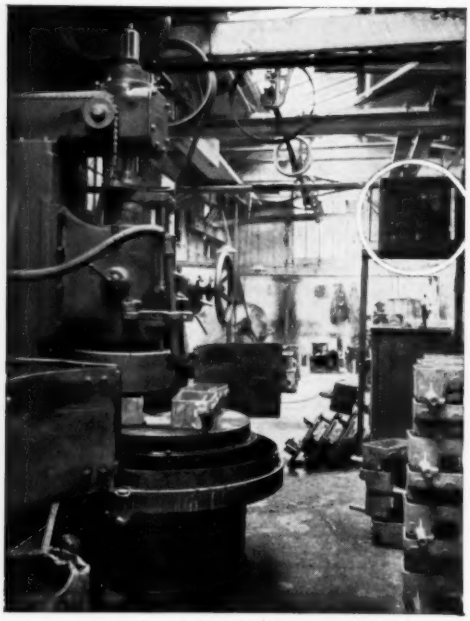

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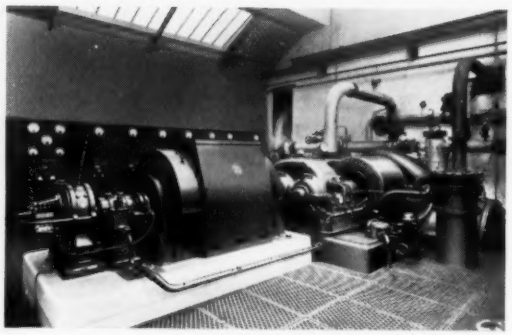

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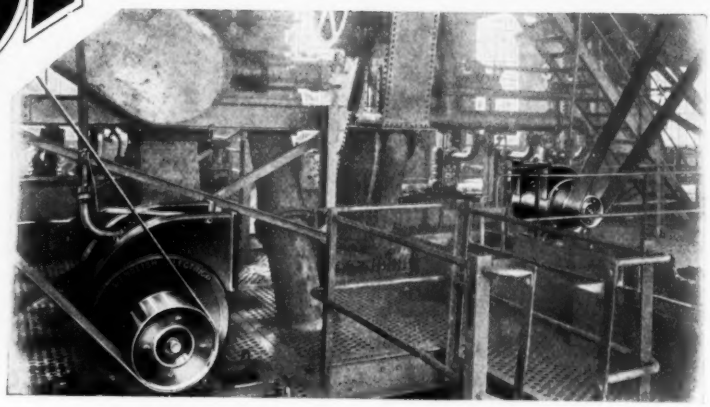

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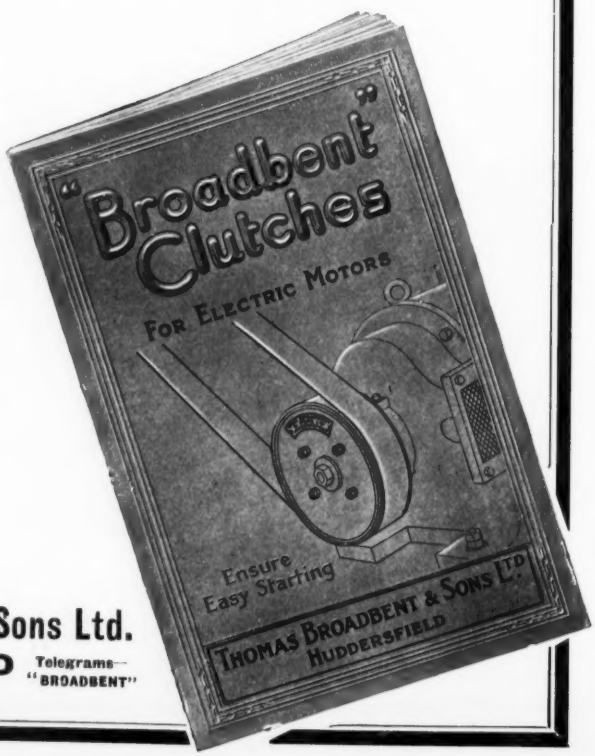

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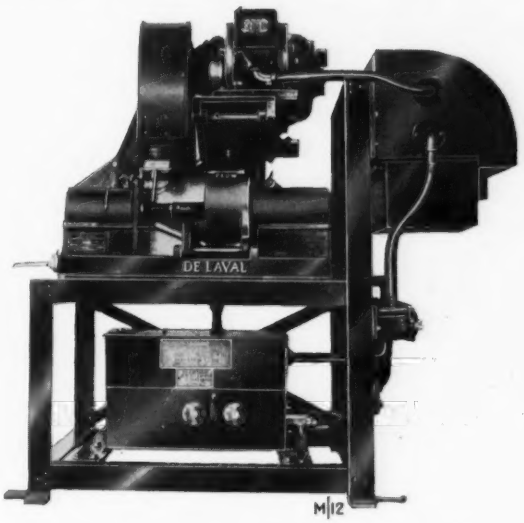

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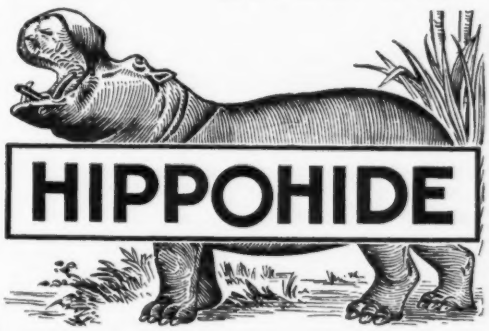

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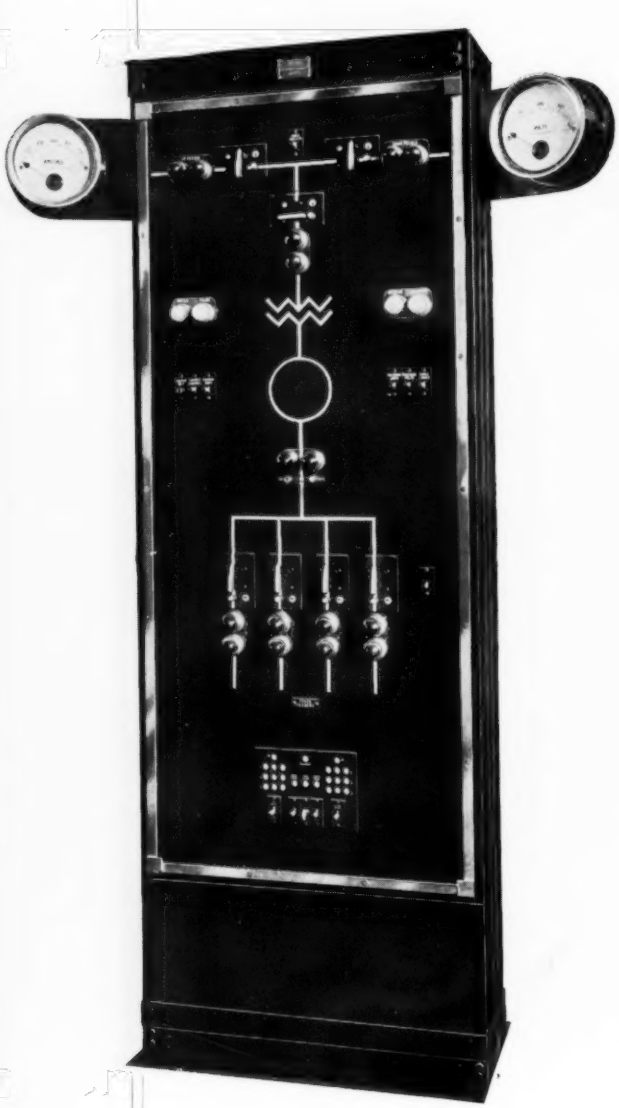

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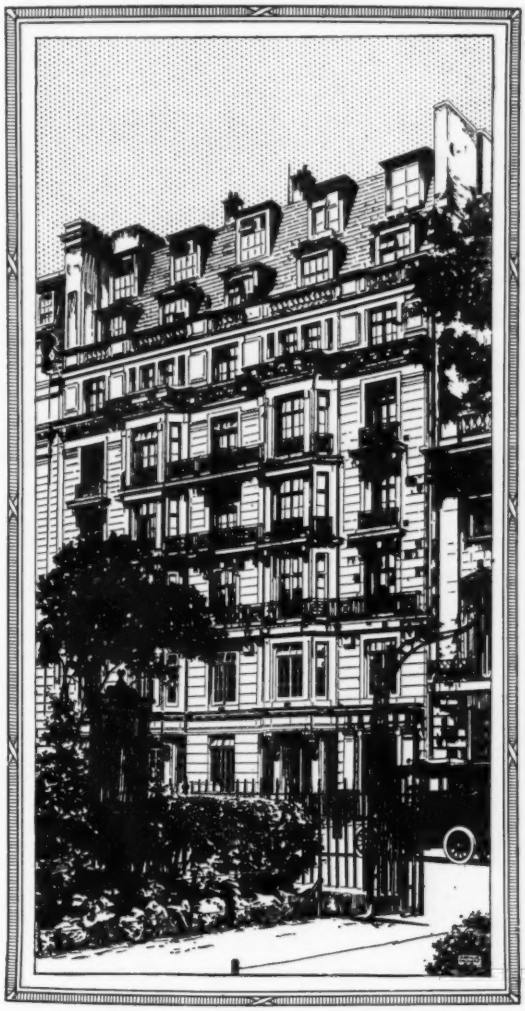

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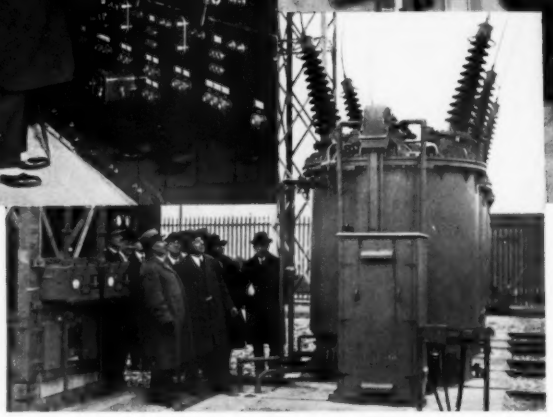
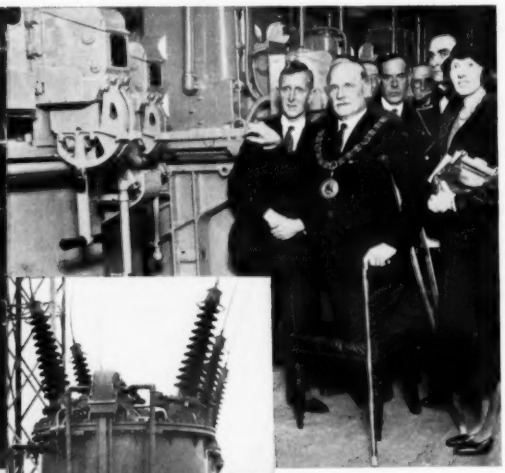
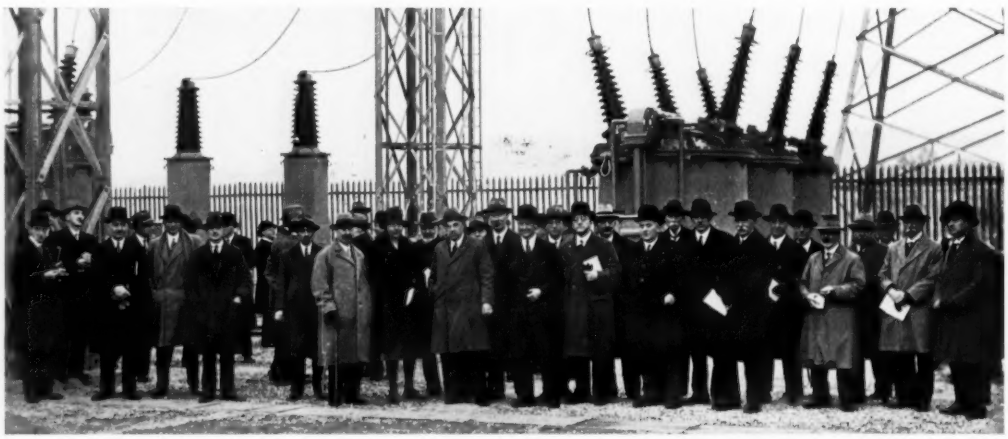
Connecting Tunbridge Wells to the "Grid"

Sir Andrew Duncan, chairman of the Central Electricity Board, operating the control board of the 132-kV. substation.





The Mayor of Tunbridge Wells, Alderman Dennis, J.P., connecting the Corporation system to the Grid Supply.



Mr. R. N. Torpy, M.I.E.E., the Borough Electrical Engineer, in the centre of a group of guests.

Two important switching installations were inaugurated at Tunbridge Wells on December 17th, the 132 kV. station of the Central Electricity Board, and a metalclad main switchboard in the Corporation's Power House. The former is one of thirteen stations of English Electric manufacture for the S.E. England scheme, and the latter is a typical example of the Company's large rupturing capacity compound-filled gear.

The English Electric Journal

Vol. V. No. 8 DECEMBER, 1931 One Shilling.

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All Communications respecting Editorial Contents should be addressed to THE EDITOR, THE ENGLISH ELECTRIC JOURNAL, THE ENGLISH ELECTRIC COMPANY LIMITED, STAFFORD.

EDITORIAL.

Incidents like those depicted on the opposite page show that the project of the Grid is fast becoming an accomplished fact—a testimony to the undiminished energy and capacity of British engineers and administrators. They demonstrate also the emergence of a new phase of electricity supply from the incorporation of the old undertakings, with their local boundaries, into a National system continuous throughout the country.

Just as the linking up of Tunbridge Wells is an example of the part the Grid will play in supplying the electrical needs of entire urban districts, the link formed by the Little Barford substation, described in one of our articles, is an example of the interconnection of the Grid with the transmission systems of large power companies whose areas of supply extend over several counties.

It is clear that with the completion of the constructional work and of a great number of links between selected power stations and the existing organ-

isations for distribution, the main task of the supply industry will be an intensive development of the use of electricity for all purposes. That is not a new conception such as the Grid was, but for that reason its successful accomplishment demands the bringing into play of new ideas to displace former limitations; the material for economic distribution will be provided by manufacturers and a bold policy of popularly acceptable charges must be devised.

The paper which we reprint on "The Application of the Induction Voltage Regulator" is important in relation to the subject of economic distribution and supply. As the largest manufacturer of automatic line voltage regulators the English Electric Company is convinced that such apparatus can be utilised on practically every system to improve the service and to procure financial benefits for the undertakings. It is as necessary a part of their equipment as are transformers and control gear.

Rival Transport Methods in the Andes.

This locomotive, built to the order of the Peruvian Corporation under the supervision of their consulting engineers, Messrs. Livesey, Son & Henderson, reached its destination last year after a journey across Lake Titicaca, which is 12,540 feet above sea level. It is operating freight and passenger traffic in a locality where the Llama is the normal means of transport.

The Little Barford Substation of the Bedfordshire, Cambridgeshire & Huntingdonshire Electricity Company.

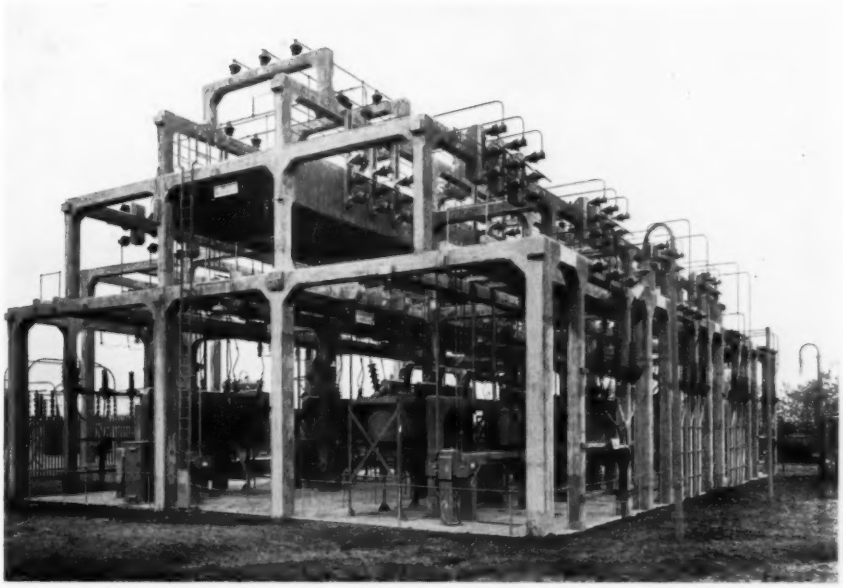

Fig 1.—General view of the 33 kV. substation.

The South-East England Electricity Scheme of the Central Electricity Board provides for the erection at some future date of a new power station at Little Barford, about seven miles east-north-east of Bedford, just within the Huntingdonshire boundary. The main 132-kV. Grid transmission line connecting Luton, Bedford and Peterborough has accordingly been diverted to a point near the proposed site for the new power station, and a transforming station erected there. The B. C. & H. Company have taken advantage of the proximity of this substation to their 33 kV. network by erecting a substation adjacent to the transforming station of the Central Board, and the contract for its construction was completed a few months ago by The English Electric Company.

The new substation, which has a number of interesting features, will enable the B. C. & H. Company to take 40,000 kVA. from the Grid network and to feed this to their distributing centres at Godmanchester, Cambridge and Hitchin. Provision has been made also for installing two 10,000 kVA. transformers for supplying a distributing system in the intermediate districts, but at present one 1,000 kVA. transformer has been deemed adequate for this purpose.

The whole of the apparatus is mounted on a reinforced concrete structure of massive design, and the apparatus itself is suitable for a normal working pressure of 44,000 volts, which gives adequate margin for operation in the damp atmospheric conditions that are prevalent in this district. The structure is provided with gangways and access ladders, but special care has been taken to ensure that an attendant cannot pass inadvertently from a section that has been made dead to another section that is still alive.

The layout (Fig. 4) incorporates a duplicate busbar arrangement with main and auxiliary busbars in the centre, and the feeder and transformer equipments on either side; a bus coupler equipment is also included. In view of the large amount of power that will be available under short-circuit conditions, oil circuit-breakers with a rupturing capacity of 750,000 kVA. have been used. They are remote electrically operated from a control room (Fig. 2) by means of direct-current solenoid operating mechanism. Busbar selection is effected by means of isolating switches operated from the ground and interlocked with the respective circuit-breakers and the bus coupler switch.

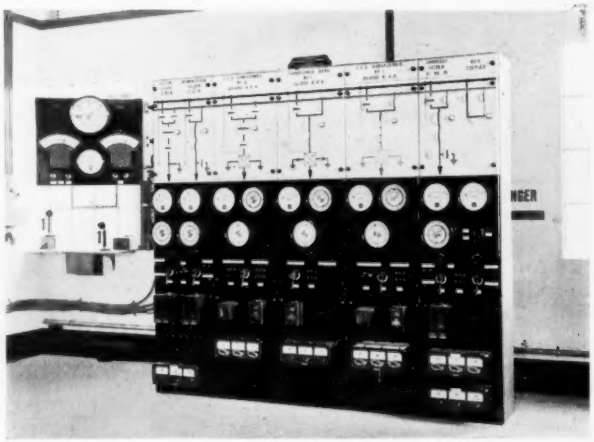

Fig. 2.—The Control Board.

In parallel with each oil circuit-breaker for the feeders and transformers there is a bye-pass isolating switch, in order that the supply may be maintained by using the bus coupler oil circuit-breaker via the auxiliary busbars when the oil circuit-breaker of a particular equipment is out of commission for inspection or other purposes. These bye-pass switches are fully interlocked to prevent incorrect operation. The feeder equipments include line isolating switches that are provided with earthing blades to ensure complete safety to an operator working on the line.

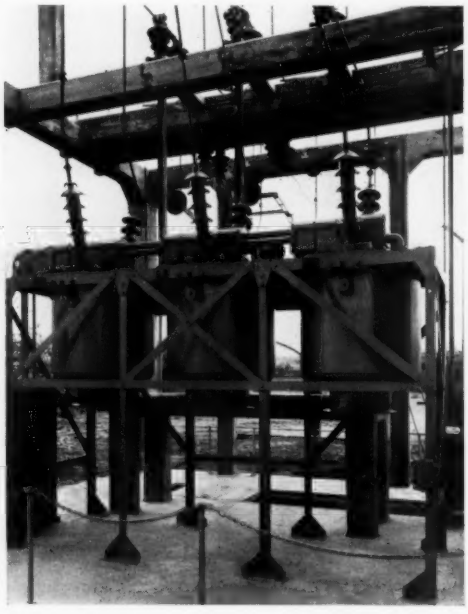

Fig. 3.—33 kV. electrically-operated Oil Circuit-breaker.

The oil circuit-breakers are standard " English Electric " OKD.3 units designed to withstand an instantaneous short-circuit of 2,000,000 kVA. and have a rupturing capacity of 750,000 kVA. As will be seen from Figure 3 the triple-pole switch comprises three single-pole units mounted together on angle iron framework with the actuating mechanism connected by pull rods to the solenoid operating gear. Each triple-pole unit is provided with tank lowering device, " on " and " off " indicators, and provision for connection to oil filtration plant.

The solenoid operating mechanism is mounted in a weather-proof cabinet and a disconnecting link board is provided in the same housing for all the small wiring connections for the solenoid and interlocking circuits, and the connections from the bushing type current transformers. This link board facilitates testing and permits the sealing ends of the multi-core cables to be removed without disturbing any small wiring or apparatus in the solenoid housing. The main

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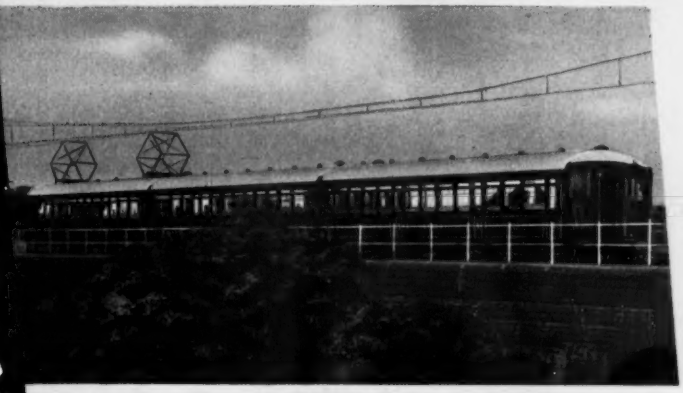

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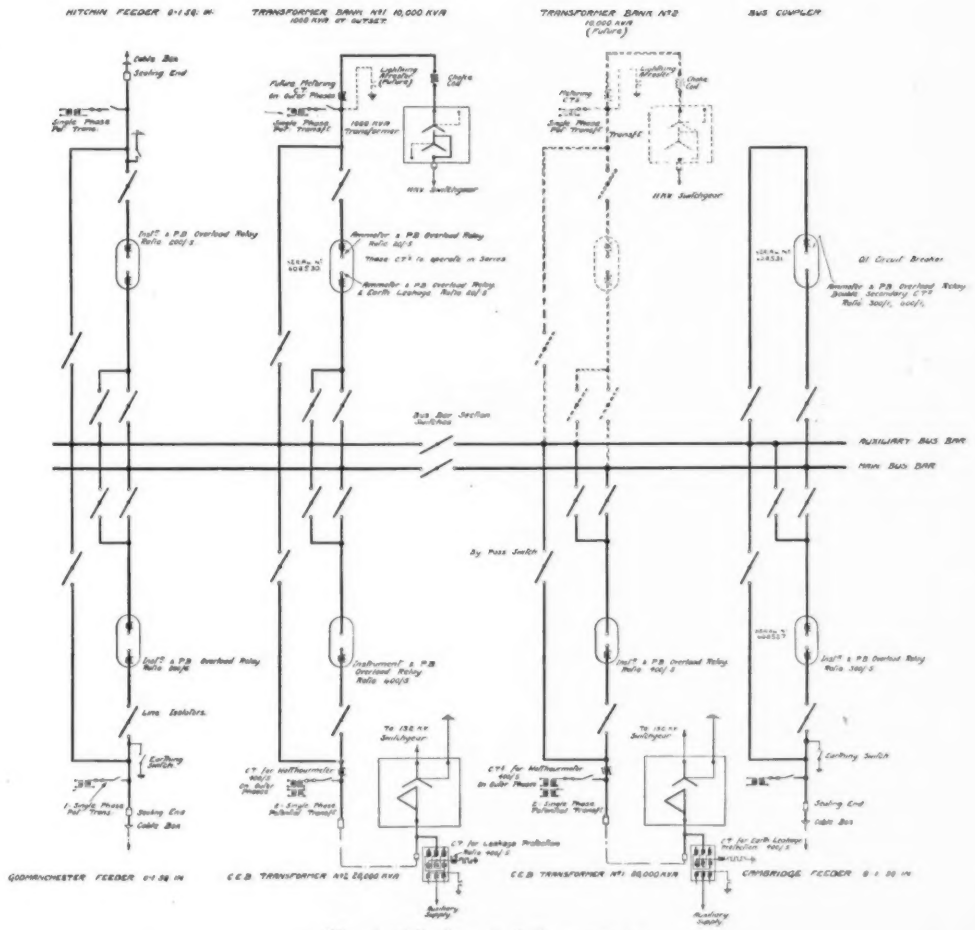


Fig. 4.—The layout of the apparatus.

contacts of the circuit breakers are of the wedge and finger type ; auxiliary sparking contacts are provided which give four breaks per phase, and thus enable a very high speed of break to be attained without the attendant disadvantage of high plunger bar velocity. The tanks are of cylindrical form of heavy boiler-plate, and are constructed to withstand a test pressure of 200 lb. per sq. in. Condenser type terminal bushings are employed protected by porcelain insulation ; they pass through bushing-type current transformers for the operation of protective relays and instruments.

The bus section switches, the busbar and line isolating switches and the bye-pass switches are of the rotating centre-pillar type. With this design there is no possibility of the switch opening under short-circuit conditions. The contacts are of the finger type, protected against snow and sleet by suitable covers, and the insulators have a dry flash-over test value of 230 kV. Two types of operating mechanism are used for the isolating switches, namely, push-and-pull rods when the switches are mounted vertically, and torque shaft drives when the switches are horizontal ; there is little difference in the mechanism itself. The coupling between the operating lever and the mechanism in the former case is effected

by means of a dog clutch which engages when the lever is raised to the horizontal position, but no movement can be made to open or close the isolating switch unless the mechanism has been released by a bolt which forms an electrically operated interlock with the other apparatus in the circuit.

The interlocks between the various isolating switches, bye-pass switches, and oil circuit-breakers are as follows :—

(*a*) An electrically-operated bolt on the bus coupler equipment to ensure that the two isolating switches on either side of the oil circuit-breaker cannot be closed or opened unless the circuit-breaker is in the open position.

(*b*) A similar interlock between the main and auxiliary busbar isolating switches. This ensures that these switches cannot be closed at the same time if their corresponding oil circuit-breaker is in the open position, but it permits both switches to be closed or either one of them to be opened when the corresponding oil circuit-breaker and the bus coupler circuit-breaker with its complementary isolating switches are all closed. This interlock does not prevent the two busbar isolating switches being opened together when the main oil breaker is open.

(*c*) A similar interlock between each oil breaker and its bye-pass switch to ensure that the breaker is closed before the bye-pass switch can be opened or closed.

(*d*) A combined mechanical and electrical interlock on each equipment to ensure that the bye-pass isolating switch can be opened or closed only when the line isolating switch and the auxiliary busbar isolating switch are closed, and the line earthing switch is in the unearthed position. This consists of a mechanical interlock between the line isolating switch, the earthing switch and the bye-pass switch, and an electrical interlock between the oil circuit-breaker and the bye-pass switch as described under (*c*).

(*e*) A mechanical interlock between the line isolating switch and the earthing switch to prevent the line isolating switch from being closed until the earthing switch is in the unearthed position, and conversely to prevent the earthing switch from being moved into the earthed position unless the line isolating switch is open. In addition an electrical interlock of the bolt type ensures that the bye-pass switch is open before the earthing switch can be closed.

There are one or two points in connection with the busbars and connections that are of sufficient interest to deserve special reference. The material used is hard drawn copper tube, and the connections to apparatus are made by substantial clamps and tee connectors designed to minimise corona losses. The busbars and connections are supported on pin type insulators, precisely similar to those used in the construction of the isolating switches, and like them capable of withstanding a dry flash-over of 230 kV. The connections to the oil circuit-breakers terminate in short flexible connecting pieces, and preceding this a portion of the tubular connector is arranged so that it can be easily removed. These details greatly

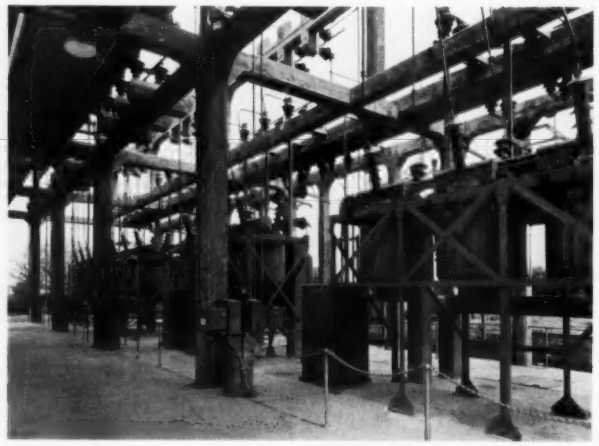


Fig. 5.—Circuit-breakers and Isolators with Operating Boxes.

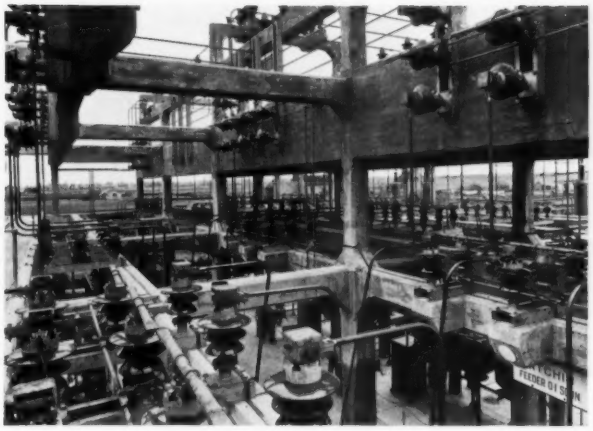


Fig. 6.—Horizontal and Vertical Isolating Switches.

facilitate the dismantling of the oil circuit-breaker bushings at any time, without extensive interference to the connections. The bushing type current transformers, which are accommodated in pockets attached to the inside of the circuit-breaker covers, are designed of a volt-ampere output and of such an accuracy as to permit the operation of power factor indicators and indicating wattmeters from them. The current transformers for metering the two C.E.B. transformer equipments are of the wound primary type, with an output of 40 V.A. at precision accuracy. They are oil filled, and fitted with a single bushing of the concentric type ; the windings are braced to withstand the maximum short-circuit conditions.

The potential transformers are single-phase oil-immersed units with an output of 200 V.A. at class B accuracy. They are of normal design, and have the same dry flashover as the insulators used throughout the station. Each transformer is protected by two 33 kV. high-resistance fuses of the replaceable cartridge type accommodated in porcelain tubes.

Protection of the feeders is effected by means of triple-pole inverse time-limit overload relays, with definite minimum time settings, and the transformer equipments are protected by an overload relay and a single-pole instantaneous Fawsett-Parry earth leakage relay. The overload relays on the feeder equipments form a standby protection to the balanced-voltage compensated pilot-wire protection that is provided.

The control board for the station is situated in a control room outside the main enclosure. It is of the type that has been standardised by the English Electric Co. for modern remote control switchgear installations, with the control apparatus and instruments mounted on panels of insulating material, which are enclosed at the back by sheet steel cubicles having separate access doors to the individual sections. This construction results in a self-supporting board, with the whole of the connections protected by a dust- and vermin-proof enclosure. A mimic diagram on the upper part of the board contains automatic semaphore indicators, which show the position of each isolating switch, oil circuit-breaker, bye-pass switch, etc., and these indicators are operated directly from auxiliary switches on the apparatus in question.

A feature of interest is the provision of white indicating lamps to show when an oil circuit-breaker has opened automatically due to some faulty conditions.

The indicating wattmeters, power factor indicators and ammeters are grouped on the centre panels with the control switches for the oil circuit-breakers and the synchronising plugs and low-tension fuses. The bottom panels are devoted to the accommodation of the protective relays.

Acknowledgment is made to the Bedfordshire, Cambridgeshire & Huntingdonshire Electricity Company for their kind permission to publish this description.

Some Recent Steam Turbine Plants of Medium Size.

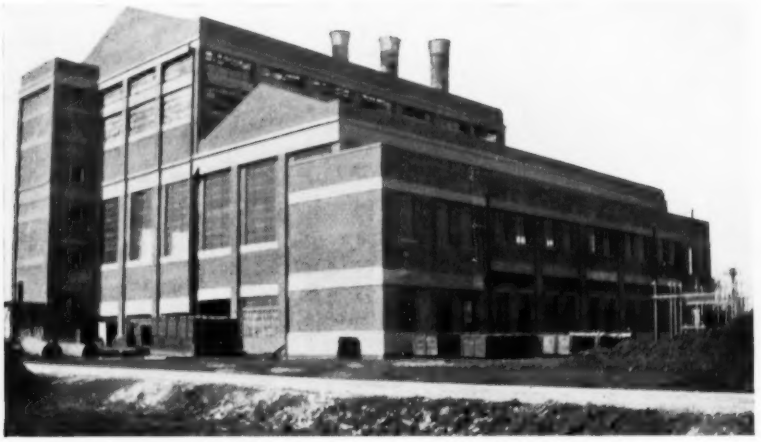


Fig. 1.—The Power Station at Atf.

From time to time a review is given in these pages of the steam turbine contracts that have been carried out, more particularly for machines of large output. In this article reference is made to a number of machines of medium output up to 6,250 kW., and apart from those technical features which represent modern development in design, there is special interest in observing that the plants are distributed throughout many different countries, including Egypt, Persia, India and Canada. The description of the three units installed at the Atf power station, Egypt, includes information already published in "The Power Engineer," to which Journal acknowledgment is made also for the loan of blocks.

Towards the end of 1930 The Egyptian Government placed a number of contracts for an important scheme of land reclamation, which included the equipment of a steam power station at Atf, which is situated about thirty-five miles east of Alexandria on the river Nile. This station contains three "English Electric" turbo-alternator sets, each of 2,500 kW., and a large amount of auxiliary plant also supplied by the Company, to which reference will be made later. Each unit consists of a 3,000 r.p.m. turbine designed for steam at a pressure of 425 lb. per square inch, superheated to 662 degrees F., and a vacuum of 94 per cent.; the alternators generate at 3,300 volts.

When the order for these turbines was received it was recognised that owing to the somewhat high steam pressure the ordinary design of mechanically operated nozzle control gear would not give the best results, and a more appropriate design was accordingly worked out and tested in the Company's Experimental Department. This new design gave such good results that it was decided to incorporate oil-operated nozzle control gear in the turbines. This development has proved so valuable that it is being adopted on the Company's larger turbines with the elimination of the heavy levers previously used for operating the governor valves; moreover, it was found that the parts of the new design are cheaper to manufacture as well as being more efficient and neater in appearance.

The same principles have been maintained as with the older design. All steam to the turbine passes through the main control valve and the subsidiary valves are operated from the main relay cylinder, but instead of operating these valves mechanically each has its own

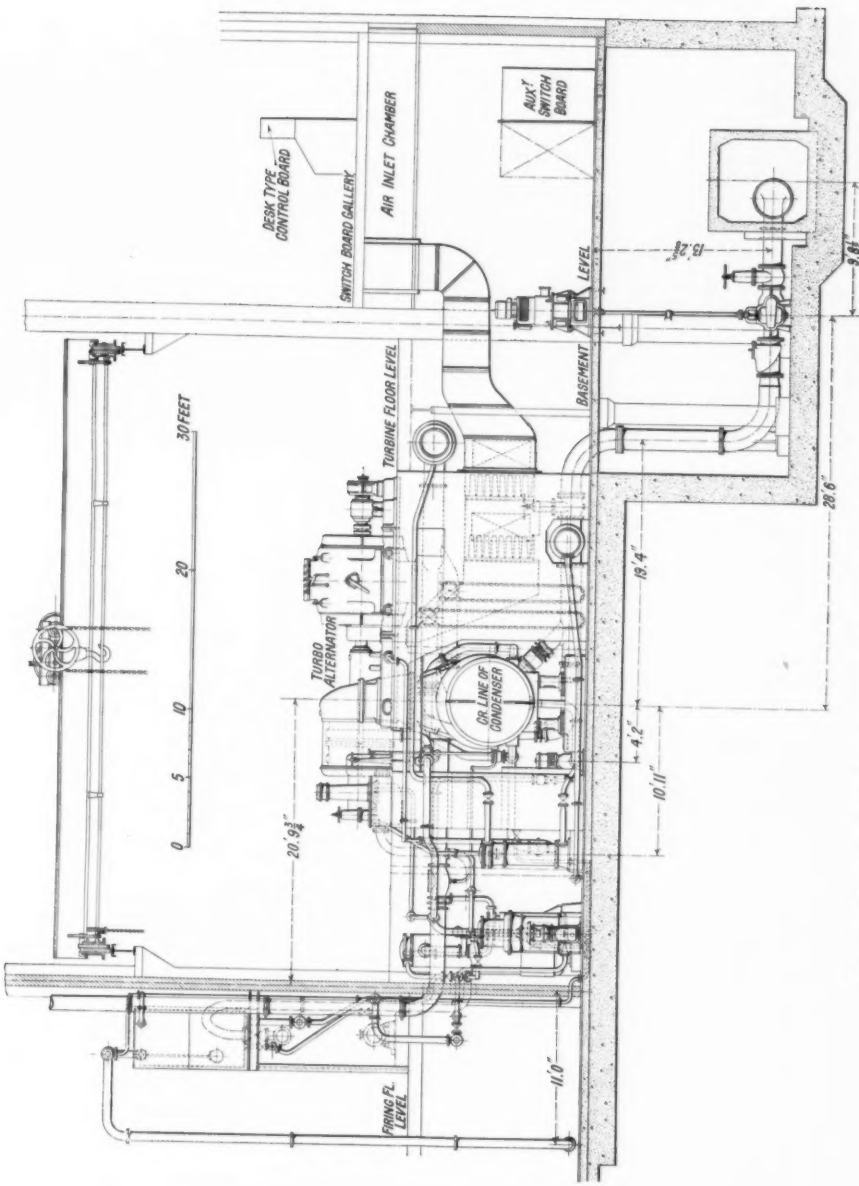


Fig. 2.—Cross Section of Aff Power Station showing general arrangement of 2,500 kW. sets.

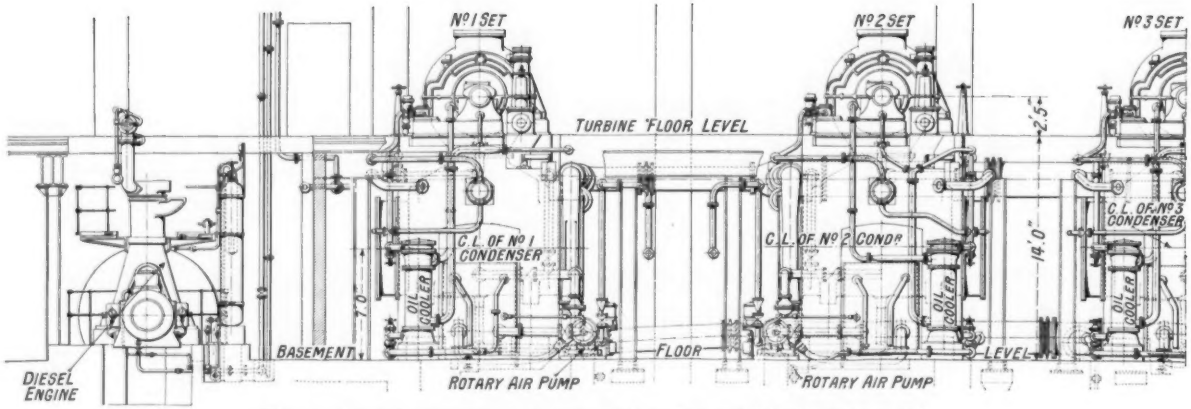


Fig. 3.—General arrangement of Steam Turbine Sets and Diesel Engine at Atf.

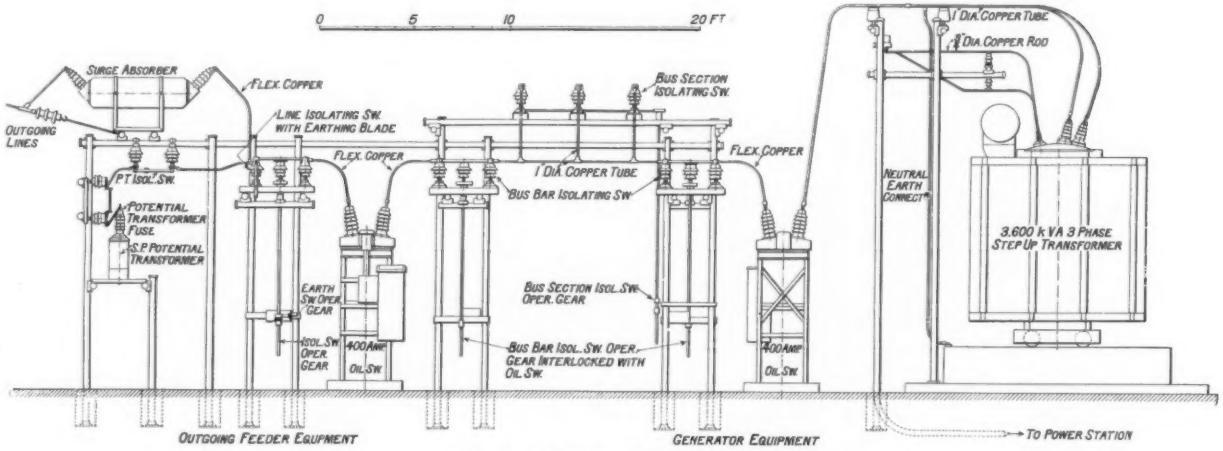


Fig. 4.—3.3/33 kV. outdoor substation at Atf.

servomotor system consisting of an oil-operated cylinder controlled by means of a rotary valve. This rotary valve is constructed in two portions, one of which is connected to the controlling mechanism and the other to the spindle of the steam valve. By this means a position of equilibrium is arrived at after each change of speed or load, and all possibility of hunting is eliminated.

The turbines are of the horizontal impulse type with stainless steel blading throughout, and each unit has an overload capacity of 15 per cent. continuously and 50 per cent. for two minutes.

A condenser of the two-pass surface type is provided for each turbine unit, and is designed so that one half of the water side may be shut down for cleaning while the turbine remains in operation. The cooling water is drawn from a canal by means of an underground culvert, and circulated through the condenser by motor-driven vertical spindle pumps, four of which are provided, one acting as a standby ; the pipework is arranged so that any of the pumps can supply any condenser.

Each turbine is bled from one point for low pressure steam to the evaporator and de-aerator. The vapour produced in the evaporator is led to the evaporator heater where its latent heat is given up to the condensate, and the water resulting from condensing the vapour is led to the drip cooler. The bled steam supplied to the evaporator gives up its latent heat to produce vapour at a lower pressure, and the resulting water is led through a trap also into the drip cooler. The combined evaporator heater and evaporator coil drains are led through a trap into the condenser. Heating of the condensate in its passage through the de-aerator is carried out by direct contact, therefore the condensate resulting from the bled steam is dealt with in the same manner as the main condensate.

Condensate is delivered normally in turn through the drip cooler and evaporator heater, to the inlet of the de-aerator. After passing through the spray nozzles in the de-aerator, it is withdrawn by the de-aerator extraction pump and delivered to the boiler feed-pump suction main. The surge tank is connected to the condensate main between the evaporator heater and the de-aerator. Make-up water treated by the evaporator is taken from the circulating water system.

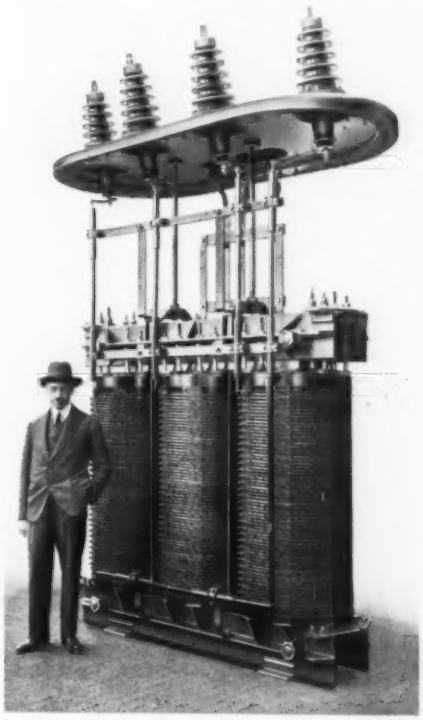


Fig. 5.—One of the 3·3/33 kV., 3,600 kVA. Transformers for Atf.

Cooling air for the alternators is impelled by fans mounted on the rotors. It is drawn from outside the building through a special air-chamber which is connected by ducts to air filters of the viscous type, in the foundations. Two filters in series are supplied with each machine. Each alternator is directly connected to a 3,300/33,000-volt transformer of the oil-immersed self-cooled core type for outdoor service, and with a normal rating of 3,600 kVA ; one of these units is illustrated in Fig 5.

For obtaining a supply for the power-house auxiliaries two 500-kVA. 3-phase core type, outdoor service transformers have been pro-

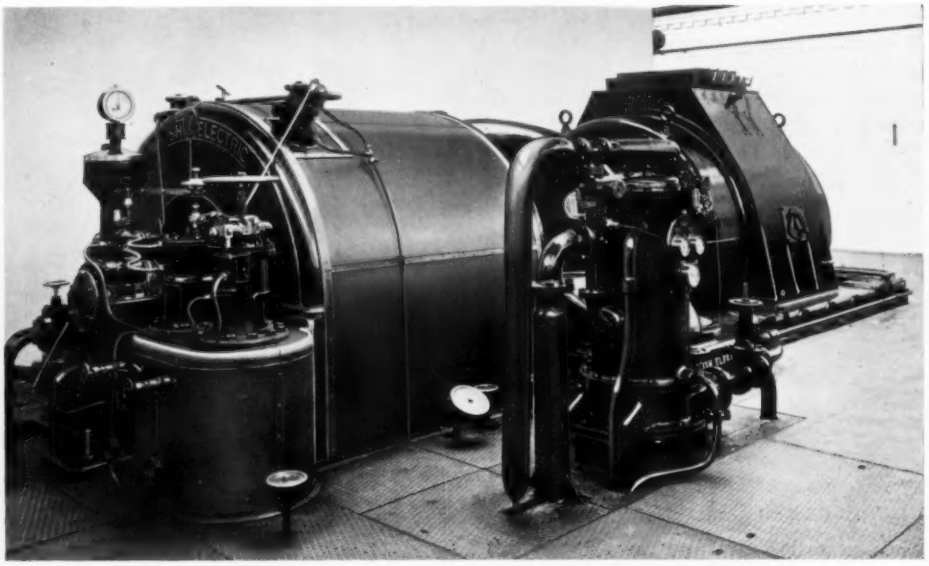


Fig. 6.—3,750 kW., 3,000 r.p.m., Turbo-alternator set in Reading Power Station.

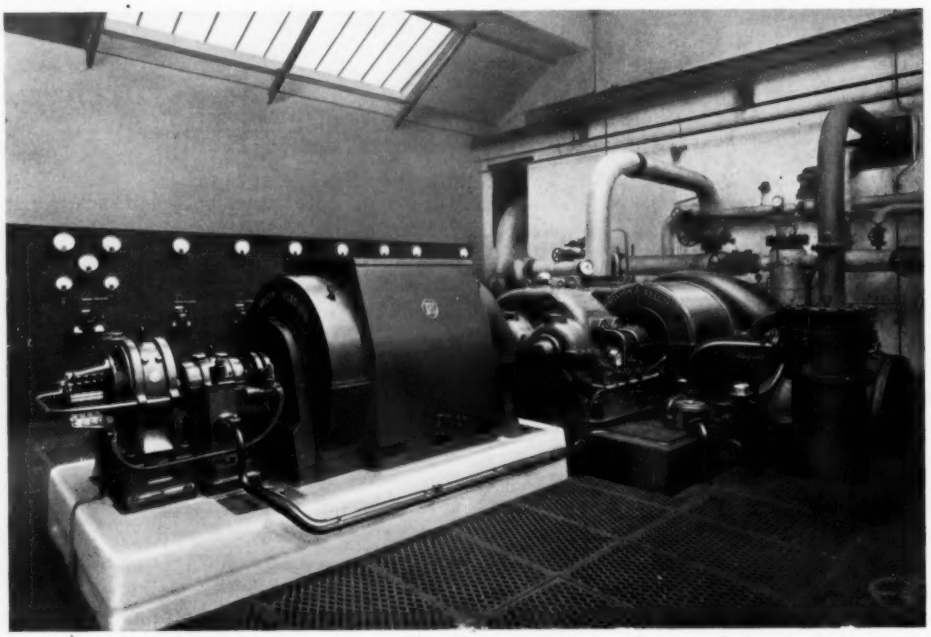


Fig. 7.—2,000 kW., Surface-type, geared Turbo-alternator set at Whetley Mills, Bradford.

vided, one transformer acting as a standby to the other. These transformers step down the pressure of 33 kV. to 220 volts, 3-phase. A house set has also been supplied, consisting of a 4-crank Diesel oil engine, direct-connected to a 220-volt, 3-phase, 200-kW. alternator. This engine set runs at a speed of 214 r.p.m. and is of English Electric standard design and construction. In addition to the usual accessories for this set, there is a main fuel storage tank, which is erected on the east side of the station, alongside the fuel storage tanks in connection with the boilers. A belt-driven pump driven from the engine shaft is used for pumping the engine cooling water to a tank erected on the roof of the Engineer's office, so that this cooling water will flow by gravity through the engine. A motor-driven exciter has also been supplied, suitable for exciting any one of the turbo-alternators or the alternator coupled to the diesel engine.

For controlling the turbo-alternators with their direct-connected step-up transformers, remote electrically operated outdoor-type switchgear has been provided, with a desk-type control board placed in the switchboard room. Auxiliary services are controlled by a 14-pillar ironclad board in a room on the condenser basement level. A 300 amp.-hour 125-volt battery, with appropriate charging gear, has been provided to operate the remote controlled switchgear and also for emergency lighting. The majority of the motors for driving the various auxiliaries are English Electric standard 3-phase, squirrel-cage or slip-ring machines. There is no switching on the 3,300-volt side, and the output of the station is stepped up to 33 kV. and controlled by the outdoor substation of which a sectional diagram is shown in Fig. 4.

A turbo alternator set of some interest is that illustrated in Fig. 8, which shows a 6,250 kW. unit that was put into service in the Maccan (Nova Scotia) Power Station of the Canada Electric Company a few months ago ; it is a 60-cycle plant with single-cylinder turbine running at 3,600 r.p.m. and operates with steam at 250 lb. per square inch, 600° F.

Of the many sets of medium size for this country a representative example has been selected from those supplied for public service and for industrial power stations. In the former class is a 3,750 kW. unit that was started up last December by the Reading Electric Supply Company. This is a standard 3,000 r.p.m. unit with " English Electric "

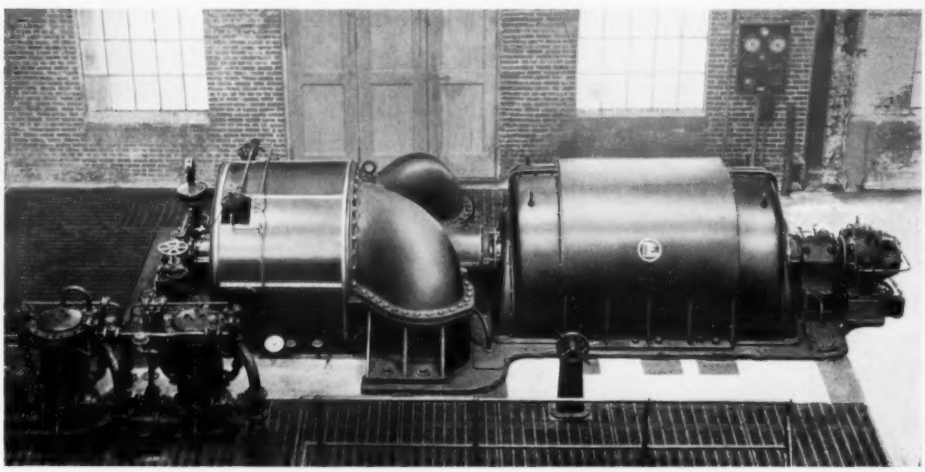


Fig. 8.—6,250 kW., 3,600 r.p.m., 60-cycle Set in the Maccan Power Station of the Canada Electric Company.

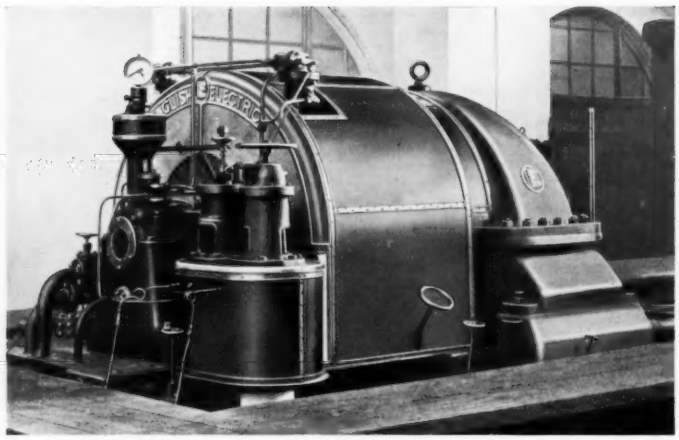


Fig. 9.—3,750 kW., 3,000 r.p.m. Turbine for Hyderabad.

condenser, and is illustrated in Fig. 6. The industrial plant is of a somewhat more novel design, in that it is of the non-basement or surface type. The unit in question is illustrated in Fig. 7 in operation at the **Whetley Mill of Messrs. Daniel Illingworth, Ltd.**, of Bradford, the changeover of whose mill is an interesting example of industrial electrification. Formerly the mill was driven by three steam engines aggregating 3,000 H.P. that occupied a large amount of space, and with 2,000 feet of shafting and five or six miles of belting, represented a weight of over 600 tons ; all this material has been replaced by a 2,500 kVA. geared turbo-alternator set and modern motor drives having a total weight of less than 100 tons. The turbine operates with steam at 220 lbs. per square inch, and 650° F., and during the daytime steam is bled at a pressure of 10 lbs. per square inch for process purposes. The production of the mill is high-quality worsted, and the processes, beginning with the sorting of raw wool, proceed through the stages of washing, carding, combing, drawing, roving, spinning, twisting, warping and winding. Over a hundred motors ranging from 10 to 75 H.P. are installed, all of " English Electric" manufacture, and the sizes of the motors and the layouts of the drives have been chosen with such care that a very high load factor is maintained as well as an installation power factor of no less than 0·83 to 0·87 without the use of any corrective apparatus.

The consulting engineer for the whole scheme was Mr. W. O. Pepper, A.M.I.E.E.

In Fig. 9 is shown the turbine for a 3,750 kW. set now being completed for **Hyderabad** to the order of H.E.H. the Nizam of that state, and under the supervision of his Consulting Engineers, Messrs. Rendel, Palmer & Tritton. Other steam plant of medium output recently constructed or put in hand includes two sets each of 2,000 kW. for **Cambridge**, a 1,000 kW. geared D.C. surface set for **Aberdeen**, and a 750 kW. mixed-pressure geared turbo-alternator set for the **Madeley Colliery Company**.

Many improvements have been introduced in the details of the designs of this range of steam turbine plant, and the modified design of governor gear referred to in the description of the Atf turbines in this article as well as new designs of small turbines and surface condensers with welded steel bodies, will be described more fully in later articles.

A New Flameproof Switch Pillar.

The total horse-power of motors installed in mines in this country at June 30th, 1929, was nearly one and three-quarter millions. This figure is a sufficient indication of the necessity for regulations that will ensure a proper degree of safety in the employment of electric power in the special and difficult conditions of mining operations. The code of regulations issued in 1911, was drawn up with a wide knowledge of these conditions and with much insight into the precautions that would be necessary and sufficient ; it has not been modified since then, but as experience has been gained in the application of the regulations, some of the clauses have been enforced with increasing strictness, as for example in the case of some that apply to apparatus, under which term switching and control gear is included. More adequate arrangements have also been made for carrying out type tests and these are now undertaken by the Mines Department, and are of a more severe character than formerly.

Important regulations concerning the use of electrical apparatus in any part of a mine in which inflammable gas, although not normally present, is likely to occur in a sufficient quantity to be indicative of danger, are those which specify that there shall be no risk of open sparking under normal working conditions, and that the apparatus shall be so protected as to prevent open sparking. Another important regulation states that adequate precautions shall be taken by earthing, or other suitable means, to discharge any conductor or apparatus before it is handled, and to prevent such parts from being made alive accidentally while persons are working on them.

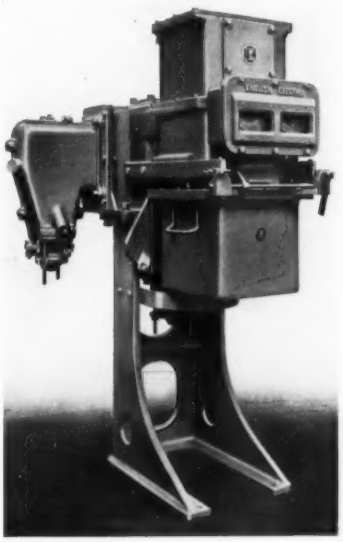


Fig. 1.—OLA Pillar in Service Condition with one straight and one angle Cable box.

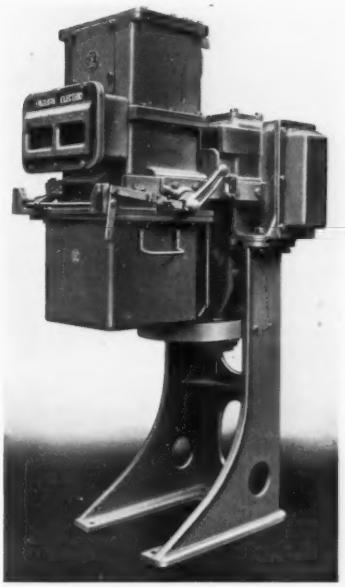


Fig. 2.—OLA Pillar with Earthing Device in position and circuit-breaker locked closed.

The apparatus illustrated in this article has been designed to meet the most stringent interpretation of the rules in every respect, and has, of course, been subjected to official testing and certification. Although it is designed primarily to be a thoroughly reliable switch pillar for use where a flameproof construction is necessary, the other features of the

design are such as should commend it for general industrial service where reliability, robustness and complete freedom from risk of shock under all conditions are important for the economic conduct of the factory.

The new " OLA " pillars are made in two sizes, the smaller of which is suitable for use up to 150 amperes at 3,300 volts, or up to 300 amperes at 650 volts, and the larger for use up to 600 amperes at 3,300 volts. Either pillar can be supplied for a considerable number of standard current ratings within these ranges, the instruments, current transformers, overload coils, etc., being also standardised in order to permit quick delivery to be made. Full advantage has been taken of the principle of compound filling, which is incorporated in the Company's larger metal-clad apparatus, and this is standard for all 3,300-volt pillars, and can be applied also to 650-volt pillars when desired. All the enclosures, including the busbar chamber, are flameproof, and of ample mechanical strength, and the conductors also

Fig. 4.—OLA Pillars are compact and instruments are of the plug-in type.

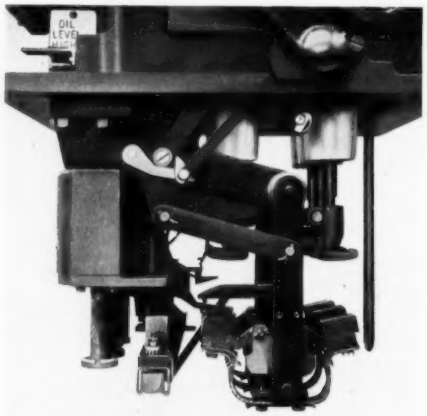


Fig. 3.—Circuit-breaker, automatic releases, and fuses in low-tension potential circuit.

are of ample section with large contact areas at all joints.

The draw-out principle is used for the isolating of the circuit-breaker and auxiliary apparatus from the busbars, and is combined with full interlocks and certain special features to eliminate any danger of improper operation or of open sparking. Provision is made also for interlocking the circuit-breaker electrically with motor starters or other apparatus. The moving carriage consists of a central portion carrying the main contacts and the current transformer, as well as the fixed contacts of the circuit-breaker ; the tank for the latter is bolted to its underneath face and the top is either closed by a coverplate or receives the potential transformer chamber when this auxiliary has to be incorporated. When instruments are required a separate flameproof box is attached and instruments of the " plug in " type are fitted behind a flameproof enclosure provided with wired glass windows.

The circuit-breaker tank is of steel plate, and contains all three phases, insulating barriers being fitted between them. The whole of the mechanism is immersed in oil, and consequently can be relied upon to operate satisfactorily under the most severe conditions with a minimum amount of inspection or maintenance work. The breaker contacts are

of the contactor type in the " OLA 1 " size, and of the laminated brush type in the larger units. A mechanical " on " and " off " indicator and an oil level indicator are standard parts of the equipment.

Complete automatic protection is available in the form of overload and no-volt automatic releases with the addition of time lags to the former if required, and a valuable feature of the design is that all the coils and mechanism of the releases are oil immersed ; this ensures a high degree of insulation, and also freedom from interference to the settings by unauthorised persons. The potential circuits are protected not only by high-tension fuses in the potential transformer chamber, but also by fuses in the low-volt coil circuit. In order to meet the demand which is sometimes made in mining installations that leakage protection shall be provided, the standard design allows for the fitting of a suitable relay in front of the potential transformer chamber, as shown in Figure 5. Amongst the special interlocks and safeguards included in the standard design, special mention may be made of the locking bar which effectually prevents opening of the lid of the potential transformer chamber until the sliding carriage has been fully withdrawn, the semi-circular guard underneath the oil tank

Fig. 6.—Earthing Device.

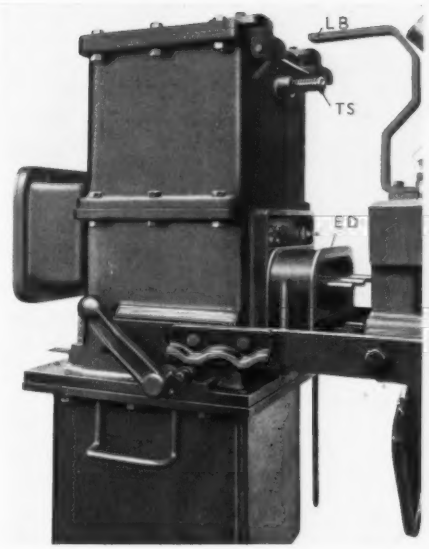


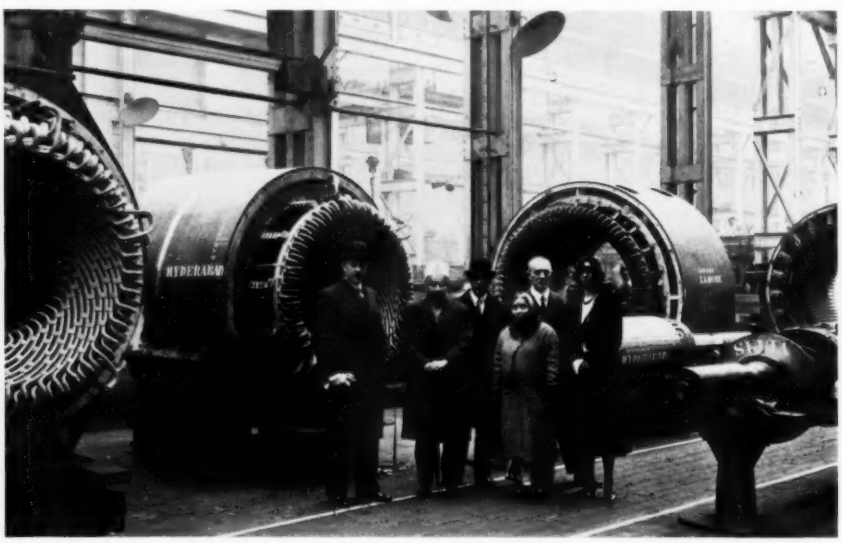
Fig. 5.—This shows the Sliding Carriage fully withdrawn and the Earthing Device E.D. in position. The Potential Transformer lid is locked by L.B. ; its circuit is opened automatically by T.S.

for a similar purpose and the special spring switch on the high voltage side of the potential transformer by means of which its circuit is opened before the sliding carriage is fully withdrawn, thus ensuring that no open sparking can occur at the main isolating contacts.

The importance of earthing circuits in a thoroughly safe way through the oil circuit-breaker has been referred to above and has been stressed in a special circular issued by the Mines Department, and " English Electric " " OLA " pillars have, therefore, been provided with an arrangement which fulfils the requirements in every respect. This consists of an earthing device, a safety lock and a warning notice displayed automatically when the earthing arrangements are in use. The earthing device illustrated in Figure 6 is a simple casting which can be fitted over the main isolating contacts when the moving carriage has been fully withdrawn ; it has guides at the two sides which engage with the slide bars on which the moving carriage rests, and a solid plate with holes corresponding to the three

busbar plugs on the moving carriage, so that these plugs are short-circuited and earthed when the earthing device is applied. When the device has been placed in position the moving carriage is pushed back as far as it will go ; it is, of course, prevented from returning to its normal working position by the width of the earthing device casting, and accordingly, although the circuit plugs make contact with the corresponding sockets in the busbar chamber, the busbar plugs, which are shorter, remain clear of the sockets connected to the busbars. At this stage the circuit is not earthed because the circuit-breaker is open, but the mechanical interlocks provide that in precisely this position, that is to say, with the busbar plugs clear of their sockets, the circuit-breaker can be closed ; this is accordingly done and the circuit thereby earthed through the circuit-breaker. It should be mentioned that special copper contacts at the side of the earthing device and on the slide bar come together with a wedging action and thus ensure a positive earth. The circuit-breaker having been closed, the separate locking lever is operated, thereby locking the circuit-breaker in the " on " position, putting the automatic releases out of action and causing a warning tablet to come into view at the front of the pillar with the wording " Earthed. Men on line." Provision is made for applying a padlock or other permanent lock to the locking lever.

However good the design of a switch pillar of this kind might otherwise be, its utility for mining service depends very much upon its compactness and the ease with which the cables can be connected up to it. The " OLA " pillars have been reduced to the smallest possible dimensions, particularly in height, consistent with the necessary technical features, and a great deal of thought has been given to the design of cable outlets and trifurcating boxes. Boxes are available for any type of armoured cable, and to meet practically any combination of incoming and outgoing cable positions. The illustrations show several combinations of straight and angle types of box.



Rao Bahadur Sardar M. V. Kibe, Deputy Prime Minister, Holkar State, Indore, and Mrs. Kibe at Stafford Works of the English Electric Company, with Mr. G. H. Nelson, the Managing Director, and Mrs. Nelson. The machines seen are for various destinations in India.

The Application of the Induction Voltage Regulator.

(This paper, read before the Institution of Electrical Engineers last year by Mr. W. E. M. Ayres, M.I.E.E., is reprinted in an abbreviated form (with additional illustrations) because it is felt that the subject is of great importance to the electric supply industry. Better voltage regulation leads not only to more satisfied consumers, but also to lower cost of distribution and fuller revenue.—EDITOR.)

SUMMARY.

This paper reviews the general application of induction regulators to feeder systems and distribution networks.

The problem of fully automatic control is dealt with and various methods of parallel working are discussed.

The point of application of the regulator in the system is considered from its practical and economic aspects, and the use of static balancers in conjunction with the regulator is outlined.

The financial aspect of induction regulator application to distribution networks is given.

Twin polyphase induction regulators giving a quadrature component for load control on closed-loop interconnectors are described.

Finally, special applications and connections of induction regulators are included.

INTRODUCTION.

On 3-phase systems where phase displacement of the voltage is of no importance it is usually most economical to apply the single 3-phase regulator, and in ring mains, or interconnections between generating stations where the voltage vector time-space position is determined by external interconnections, it is usual practice to supply twin 3-phase regulators. On distribution systems fed from a high-voltage ring main through transformers and regulators into a common distribution network it is also necessary to avoid voltage phase-displacement and twin 3-phase regulators may be used.

There are, however, instances where banks of single-phase regulators are preferable. On 4-wire distribution networks, where considerable out-of-balance load is expected, it may be desirable to regulate each voltage between phase and neutral independently, and banks of independently operated single-phase regulators would be employed.

Several connections are available for the grouping of single-phase regulator banks, but not all avoid voltage phase-displacement.

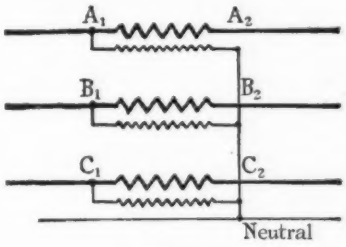


Fig. 1.

In the case of 4-wire systems, which is practically limited to low-voltage distribution networks, the regulator primary windings should be star-connected and the star point connected to the neutral of the system. The connections and voltage diagrams are shown in Figs. 1 and 2 respectively. With this connection there is no voltage phase-displacement, but it should be noted that the star point of the primaries must be connected to the neutral point, otherwise there is nothing to determine the phase voltages of the primary windings and unequal boosting may occur. If each regulator is subject to independent

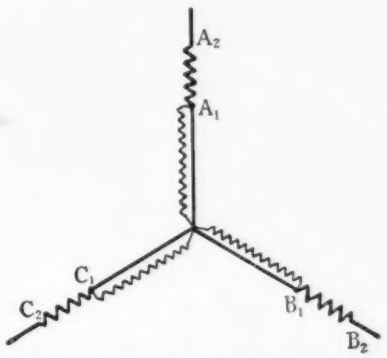


Fig. 2.—Voltage diagram of 3-phase 4-wire regulation.

automatic operation there may also be instability.

Ring mains are frequently operated at 6·6 or 11 kV, 3-wire, and where single-phase regulators are essential an interconnected-star balancer should be used with its star point connected to the star point of the regulators as an artificial neutral. Without this precaution serious troubles are likely to occur, particularly when switching the regulators into service.

Three-phase 3-wire systems may be regulated by means of three single-phase induction regulators with the primary windings connected between lines, or by means of two single-phase regulators connected " V," or " open-delta."

Under the usual conditions three single-phase regulators connected in this manner will produce a voltage phase-displacement owing to the fact that the induced voltage in the series winding is displaced 30° from the line voltage, as shown in Fig. 3. In this case, however, the maximum displacement is coincident with the positions of maximum boost or " buck," and zero displacement at neutral position of the regulator. This is the reverse of the conditions which apply to single 3-phase regulators. In another connection for 3-wire circuits the primary is in two parts, fed from two adjacent phases and wound on the same polar axis. This arrangement eliminates phase displacement, but is more limited in respect of voltage and output than are most other connections. It may be considered to be impracticable if $P < E/(20)$, where P is the internal regulator output (i.e., line kVA × percentage boost) and E is the voltage between lines. A variation of this arrangement with the secondary (series) windings divided between adjacent phases is shown in Figs 4A and 4B.

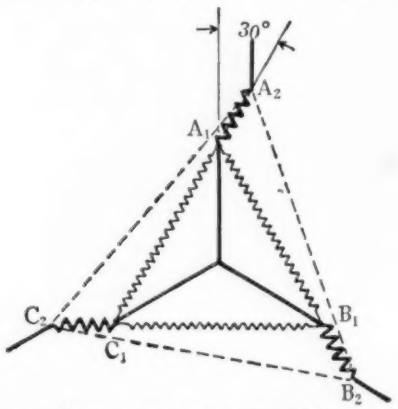


Fig. 3.—Voltage diagram of 3-phase 3-wire regulation.

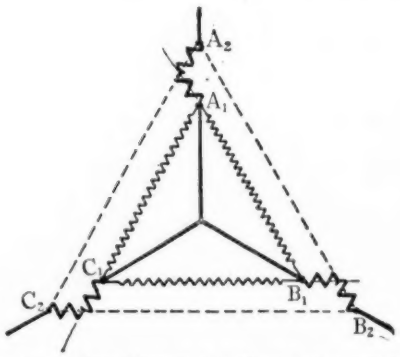


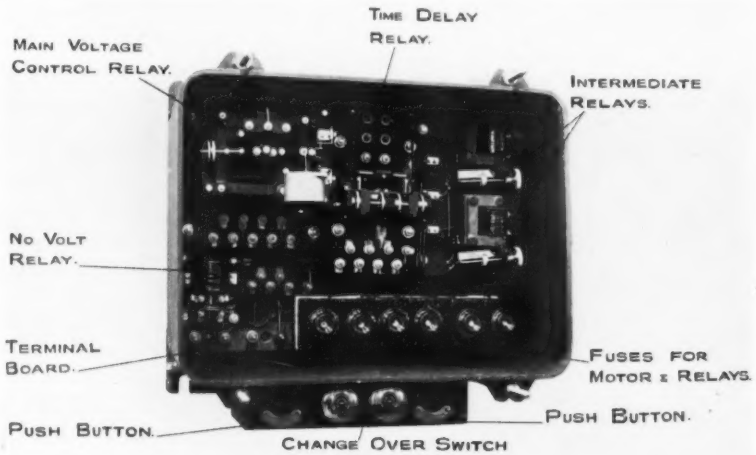
Fig. 4a.—Voltage diagram of 3-phase 3-wire regulation without phase displacement.

The further alternative is two single-phase regulators in open-delta connection as shown in Fig. 5. This arrangement overcomes the voltage displacement, but care must be taken to ensure that the shifted neutral will not cause difficulties due either to accidental earth faults on the regulated side of the system, or to upsetting the operation of the protective gear.

The various arrangements in which the primary windings are connected between phases, instead of phase to neutral, all require 15·5 per cent. increase in size of regulator, due to the 30° displaced voltage in the series winding only being effective to the extent of $\frac{1}{2}\sqrt{3}$, as will be readily appreciated from Figs. 3 to 5.

Automatic Control.

One of the outstanding features of the induction regulator is its adaptability to automatic control under varying conditions and requirements. A 3-phase regulator on a distribution system where it was originally considered doubtful whether voltage regulation was required, was found to average 240 operations per day, or over 87,000 per annum. One hesitates to think of the wear and tear, with its attendant maintenance costs, that would result from such frequent operation of switches. The actuating relays for the automatic control of the regulator, however, showed no signs of distress, and maintenance costs are



Self-contained Relay Assembly for Automatic Voltage Control by Induction Regulator.

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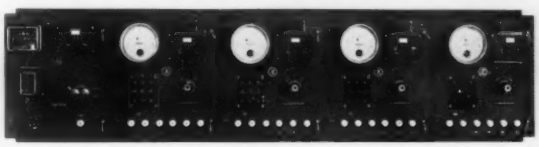

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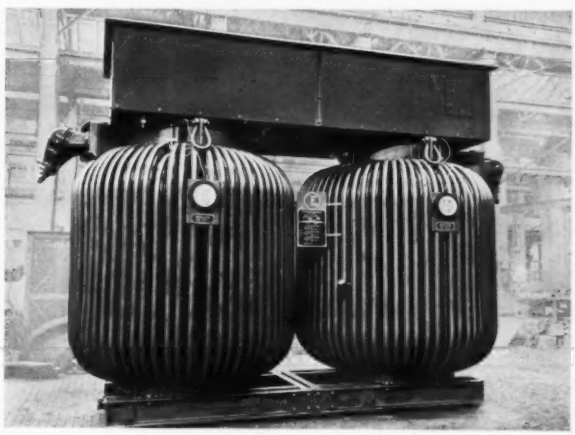

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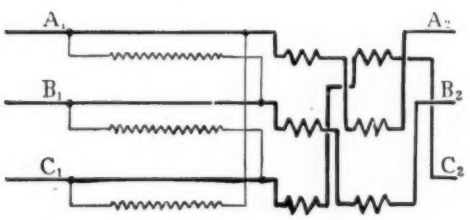


Fig. 4b.—Connections for 3-phase 3-wire regulation with split secondaries for no phase displacement.

negligible. In a works' endurance test one set of automatic gear was subjected to nearly 750,000 voltage impulses without a single faulty operation and with only one cleaning of the relay contacts. Such reliability has only been achieved by the most careful design, choice of materials and contact loading.

In essence the control consists of a sensitive voltage-control relay, a pair of interlocked motor contactors, an operating motor, limit switches and magnetic brake (see Figs. 6A and 6B). In practice there are many refinements which contribute to the reliability of operation and which are appreciated by operating engineers.

The voltage-control relay should not transmit any vibration from the a.c. excitation of the relay to the contacts, as this causes a spluttering "make" when the contacts are about to close. Reinforcement, or compounding, should be incorporated in the design so that immediately contact is made an additional torque is added to the relay, thus ensuring a firm contact. This reinforcement may be from 0·33 to 0·5 per cent. equivalent voltage variation. This reinforcement must, however, be a constant value and not due to the contactor-coil current, as the reduction in current when the contactor closes (to about 27 per cent.) often causes the relay contacts to open again; a rapid succession of closing and opening of the contactors follows without the operating motor having time to accelerate.

The contact separation should be as large as possible. A good relay will give as much as 3 mm. separation of contacts for 1¼ per cent. difference in voltage, but voltage-control relays are sometimes offered which give barely one-sixth of this amount. The author has seen cases of high-frequency welding of contacts due to a "hovering" arc when the design of relay and reinforcing has been incorrect.

According to the author's experience, the motor limit-switches should be double-pole and placed directly in the motor circuit. They are frequently placed in the contactor coil circuit, with resultant damage to the regulator if a contactor sticks or opens sluggishly, and the quadrant is driven hard up against the mechanical stops. The limit-switch operating mechanism should be designed to give a very small angle between opening and re-setting of the switches.

Where the operating motor circuit is from an auxiliary supply which is independent of the feeder being regulated, it is usual to include a no-volt relay in the automatic control apparatus. The function of this relay is to return the regulator to the minimum voltage position in the event of voltage failure on the line, so that the line is not reclosed on an excess voltage. If this relay were not included the motor would run the regulator up to the maximum-voltage position. In some twin regulators for power flow in either direction, the no-volt relay has been arranged to return the regulator to neutral, or zero boost, position in the event of line-voltage failure.

If a recording voltmeter, with high paper speed, is connected across a feeder or distribution network, there is almost always a pronounced irregular ripple in the voltage, which is the result of a diversity of load variations and switching operations. A section of such a chart is reproduced in Fig. 7. The width of the ripple band varies in individual cases from practically nothing

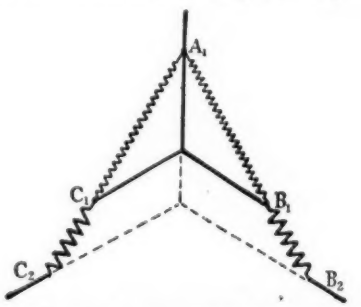


Fig. 5.—Voltage diagram of "V" or "open-delta" connection.

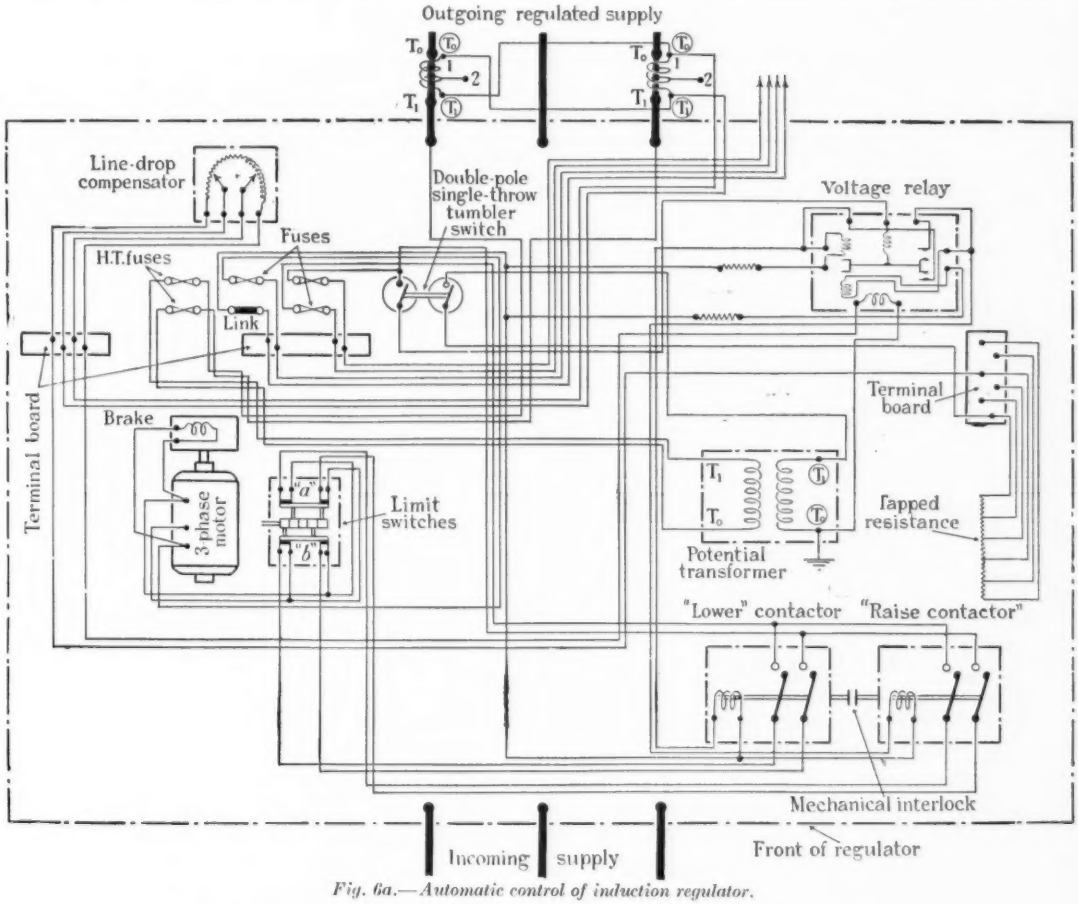


Fig. 6a.—Automatic control of induction regulator.

up to some 2½ per cent. voltage variation. It is obviously quite impossible to correct these rapid fluctuations, and the voltage control relay should be set for an amount not less than plus and minus half the ripple-band width. Also, on the above chart there is shown a sudden voltage-drop of short duration at "A." This was probably brought about by the starting of a motor on the section. It is not desired that the automatic gear should attempt to correct this class of variation, which is of too short a duration to be of any consequence, would cause unnecessary wear and tear of the operating mechanism and would in many cases be rectified before the motor had time to function. Some form of time delay is, there-

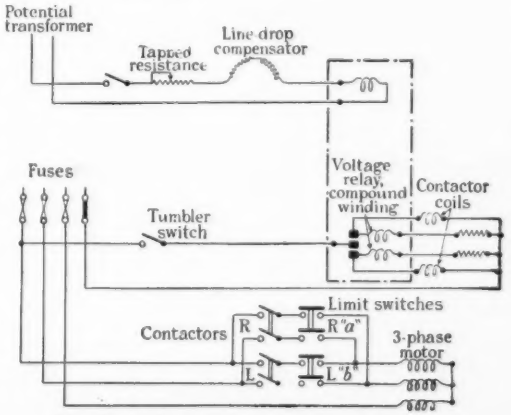


Fig. 6b.—Schematic diagram of automatic control.

fore, frequently used to prevent operation until a voltage deviation from normal is maintained for 20 to 40 seconds.

The cost of the automatic control apparatus becomes a serious item in small regulators, say, up to 50 kVA, and this necessitates the simplest possible combination of relays consistent with satisfactory operation. In equipments which are able to bear the additional expense there is considerable justification for the use of intermediate relays between the main voltage-control relay and the motor contactors. These relays reduce the loading on the control relay contacts to something like 2 VA, and this is usually accomplished on a low voltage by means of a small transformer of the bell-ringing type. The control relay is a very sensitive instrument, but when its contact loading is reduced in this manner it is able to give reliable service for an indefinitely prolonged time with the minimum of attention. The intermediate relays have a definite make-and-break action, with ample contacts, and are better able to deal with the contactor coil load, which may be from 120 to 200 VA.

An interesting problem is the control of a feeder to compensate for the load drop between two distribution centres and maintain the same voltage at either end, irrespective of the supply voltage. This has been accomplished by means of a differential relay supplied from two potential transformers and a line-drop compensator, as shown in Fig. 10. The incoming volts plus the line-drop volts are balanced against the outgoing voltage and thus provide just the necessary boost according to the load.

Parallel Operation.

It is sometimes desired to operate regulated feeders in parallel. This does not involve the use of twin regulators if means are provided for maintaining the voltage phase angle the same in all the feeders. For two feeders it is possible to couple the regulators mechanically so that they always operate simultaneously, but this frequently has disadvantages, limits the site position in the substation, and is not flexible for extensions. Various arrangements have, therefore, been devised for simultaneous operation. The scheme shown diagrammatically in Fig. 11 has been used successfully with as many as four parallel feeders, and the positioning has been so accurate that it is impossible to observe from the switchboard ammeters which is the automatically controlled master regulator and which are the "trailers." A potentiometer resistance (1) is mounted on each regulator and has its sliding contact (2) geared to the regulator rotor. A sensitive polarized relay (3) is connected between the slider of the master regulator and each of the trailers. The contacts of this relay close the "raise" or "lower" voltage motor contactors, thus restoring the "trailing" regulator to the same angular position as the master. This system is very simple, and will be recognised as an adaptation of the Wheatstone bridge and galvanometer. A centre-zero voltmeter (4) is connected between the centre point of the potentiometer resistance and the slider, and is scaled in electrical degrees displacement from neutral. It is possible by this means to bring any regulator into the same angular position before switching it into service.

The parallel operation of single-phase, or twin 3-phase, regulators may be accomplished by means of the potentiometer method, but it is more frequently desired to balance the load on the feeders irrespective of the angular position of the regulator. Where line-drop compensation is used this load balancing may be roughly obtained by connecting the line-drop compensators of one feeder to the current transformers of the adjacent parallel feeder. This is comparatively insensitive, as with 5 per cent. line-drop compensation and voltage relays set for $\pm$ 1¼ per cent., one feeder can fall to 75 per cent. load and the other rise to 125 per cent. load before there is any tendency to restore balance. A much more sensitive load balancing has been used by the author, in which

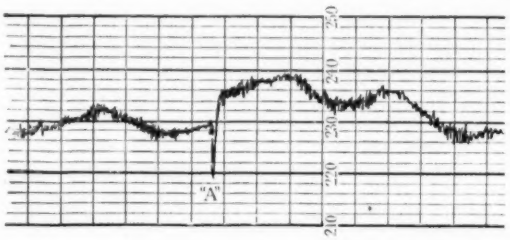
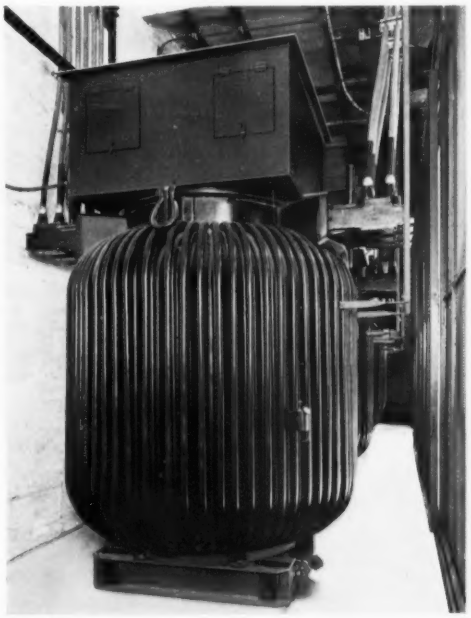


Fig. 7.—Voltmeter chart, showing ripple band.



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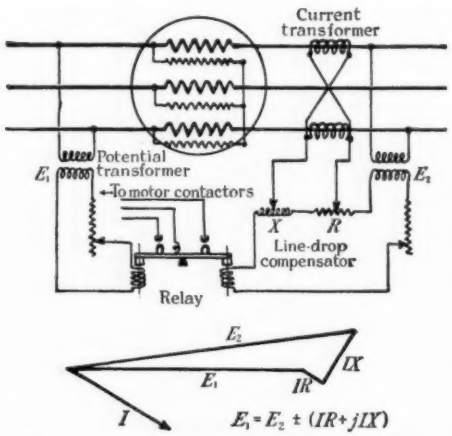

Fig. 10.—Automatic control by differential relay.

additional current transformers are used, as shown in Fig. 13, to effect the load balancing. The current transformers (1) and (3) in one feeder are connected in series with (2) and (4) in the adjacent parallel feeder. If the currents are balanced in the two feeders, or distributors, the secondary currents circulate freely, but if one feeder has a higher current the excess secondary current cannot pass through the high impedance of the other transformer and is forced through the line-drop compensators, tending to raise the voltage of the lightly loaded feeder and depress the voltage of the more heavily loaded feeder until balance is restored. These additional current transformers, used for balancing purposes only,

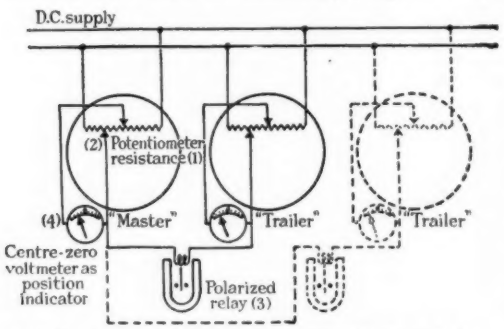

Fig. 11.—Parallel operation by potentiometer method.

may with advantage be made of a different ratio from the compensating transformers, thus enhancing the sensitivity.

Position of Regulator in Feeder.

No hard-and-fast rules can be set down for the point of application of induction regulators in a feeder. The technical and financial considerations are so varied that each case has to be worked out on its own merits. The fundamental conditions, however, can be stated.

In general, it is most economical to insert the induction regulator at the sending end of a feeder. In this position the primary winding is on the incoming constant-voltage side and the primary current has not to be passed through the regulator series windings. The internal kVA capacity of the regulator, and therefore the cost, is reduced.

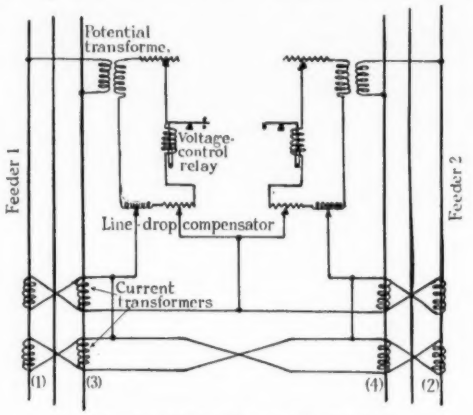

Fig. 13.—Load balancing on parallel feeders.

More important, however, is the saving in transmission, as the increased voltage at the sending end means a smaller current to be transmitted for a given kVA received. This may be utilised either as a reduction in transmission losses and in size of regulator, or to cheapen the cost of the transmission line itself. For heavy feeder-drops a balance may be found where the sum of transmission line cost, regulator cost and capitalised cost of the losses is a minimum.

(To be concluded.)

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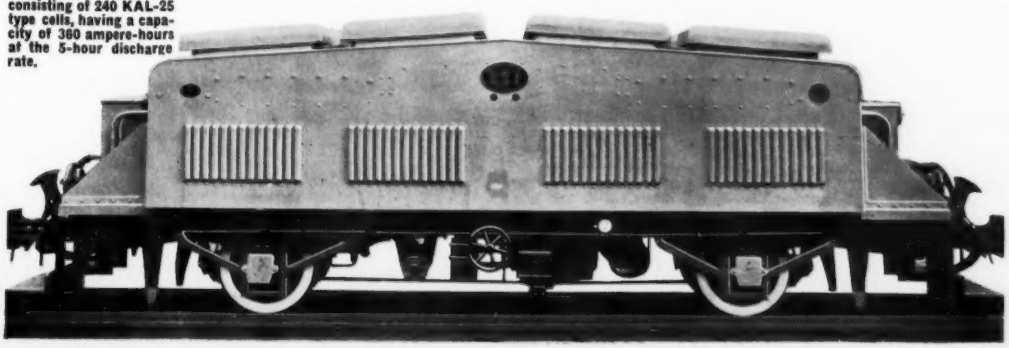

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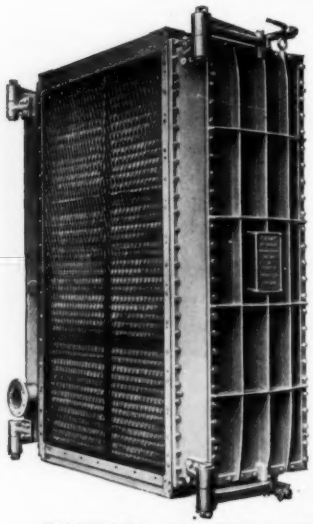

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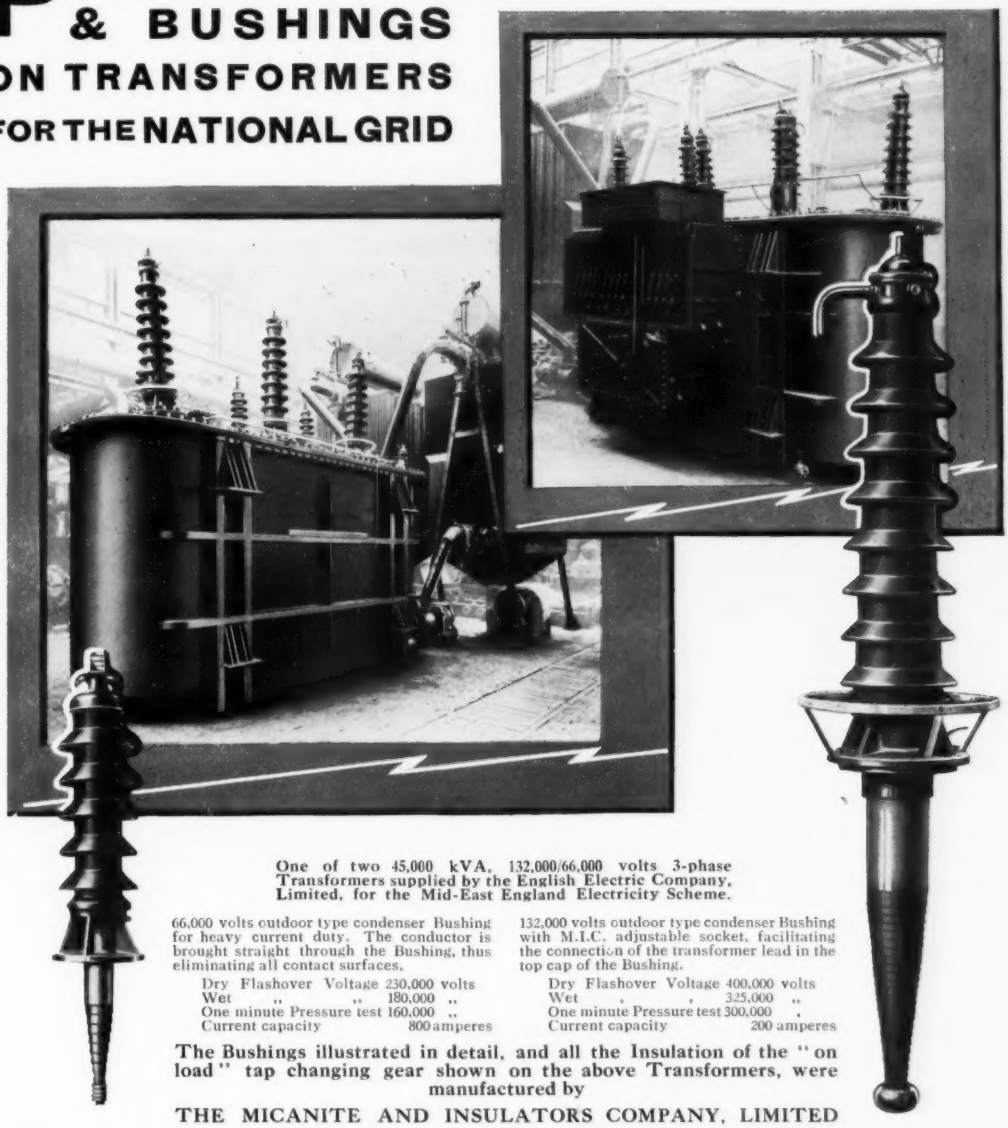

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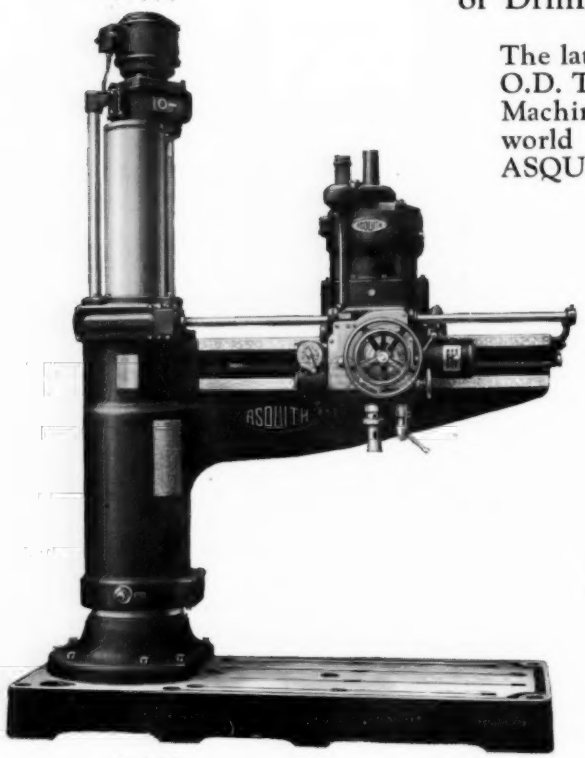

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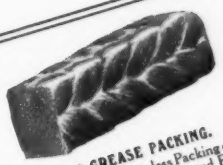

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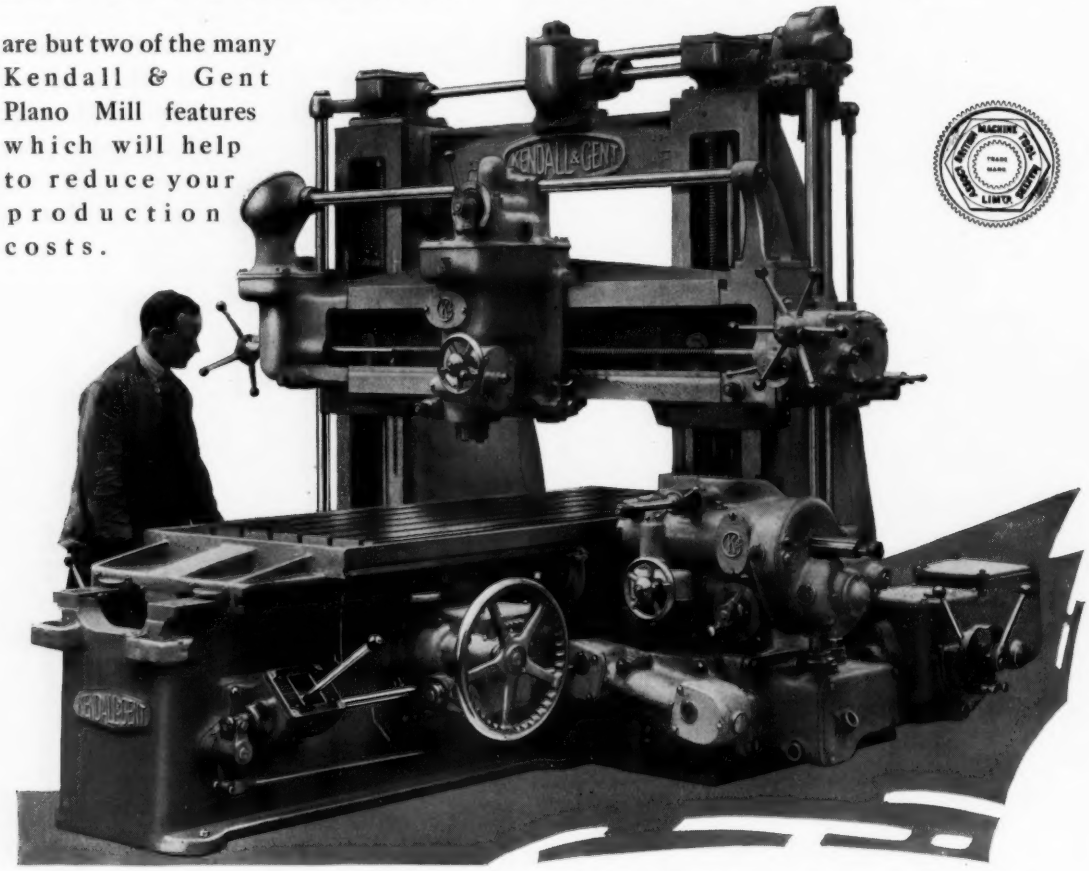

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